(54) Title: HIGH PROTEIN, HIGH FAT EXTRUDED SINKING AQUATIC FEED

(57) Abstract

A method of producing extrudates such as high protein, high fat sinking aquatic feeds is provided wherein a high protein starting material is initially preconditioned and passed through an extruder (14); in the extruder barrel (36) a zone of reduced pressure is created upstream of the die (40) for densifying the final extrudate. Fat may be added to the starting mixture at any desired point in the process, and/or may be added as a surface coating to the final extrudate. Preferably, the method further involves measuring a density value of the extrudate such as bulk density, and adjusting the magnitude of the reduced pressure conditions in the barrel in response to such measurement.

HIGH PROTEIN, HIGH FAT EXTRUDED SINKING AQUATIC FEED

BACKGROUND OF THE INVENTION

1.   Field of the Invention

The present invention is broadly concerned with a method of preparing high protein, high fat sinking aquatic feed products useful in aquatic farming operations for efficient growth of fish. More particularly, the invention pertains to such methods wherein a proteinaceous starting mixture is preconditioned and extruded with a zone of reduced pressure along the length of the extruder barrel for densification of the final extrudate; the method further includes the step of adding fat to the starting material or extrudate so that the final product has a total fat content of from about 10-40% by weight.

2.   Description of the Prior Art

Aquatic farming is increasingly becoming a major industry, especially in light of the increasing consumer demand for fish and fish products. To give but one example, salmon are often raised in confined sea water ponds and fed specialized diets designed to maximize growth. It is known that salmon feeds should have a very high fat content for most efficient fish growth. At the same time, an effective feed must have a specific gravity of greater than 1 so that it will sink, and must have appropriate hardness and other qualities which will induce salmon to eat the feed.

It has been known in the past to provide relatively large extruded pellets having high protein and oil contents for use in salmon farming. however, these pellets have been produced using small, low capacity equipment and techniques which render the product very expensive. There is accordingly a need in the art for more efficient techniques for producing high protein, high fat sinking aquatic feeds which can be carried out on a high volume basis to reduce feed costs and which give consistent feed properties.

SUMMARY OF THE INVENTION

The present invention overcomes the problems outlined above and provides an efficient, high-output process for the production of large diameter, high protein, high fat sinking aquatic feeds with integrity. Broadly speaking, the method involves first

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providing a starting mixture, including 15-55% by weight protein (more preferably from about 25-45% by weight protein) and at least about 1% by weight starch (most preferably from about 7-15% by weight starch). This starting mixture is first preconditioned by adding moisture thereto and subjecting the starting mixture to
5   conditions of elevated temperature and agitation. Thereupon, the preconditioned starting mixture is fed into and through an extruder having an elongated barrel and an elongated, axially rotatable, flighted screw therein with an endmost extrusion die. This treatment forms self-sustaining extrudate having a specific gravity of greater than 1. During passage of the preconditioned starting mixture through the extruder, a condition
10   of reduced pressure is created within the barrel upstream of the die for densifying the preconditioned starting mixture. Furthermore, the overall method involves the step of adding fat to the starting mixture and/or the final extrudate so that the latter has a total fat content of from about 10-40% by weight. Thus, liquid fat may be added to the starting mixture initially, during preconditioning or during passage through the extruder
15   barrel; also, fat may be applied directly to the extrudate after passage through the extrusion die.

              In particularly preferred forms, the method includes the step of measuring a density value of the extrudate emerging from the extruder and adjusting the magnitude of the reduced pressure conditions within the extruder barrel in response to such
20   measurement. Normally, the bulk density of the extrudate would be measured and this data used as a guide for alteration of the pressure conditions within the extruder barrel.

              During the preconditioning step, the starting mixture is subjected to a temperature of from about 75-98°C (more preferably from about 90-97%) for a period of from about 150-200 seconds (more preferably from about 170-190 seconds). The
25   purpose of preconditioning is to initially moisturize and partially cook the starting material prior to entrance thereof into the extruder barrel. Advantageously, the material leaving the preconditioner has a moisture content of from about 20-60% by weight, and more preferably from about 21-23% by weight.

              In the extruder, the preconditioned starting material is subjected to conditions
30   of elevated heat, pressure and shear. Normally, the temperature conditions in the barrel are such as to achieve a maximum temperature of from about 50-95°C, and more preferably from about 65-80°F. Normal maximum pressure conditions are from about 100-500 psi, and more preferably from about 150-300 psi. The preferred temperature profile within the extruder barrel is such that the preconditioned starting material is
35   heated to a temperature maximum just prior to reaching the zone of reduced pressure.

Thereafter, the temperature of the material is generally reduced and the region of the barrel downstream from the reduced pressure zone is a forming region where the material is compacted prior to ultimate extrusion.

The reduced pressure zone of the extruder barrel is normally created by drawing a partial vacuum therein. Such partial vacuum typically has a magnitude of from about 2-15 in. H_2O and more preferably from about 7-13 in. H_2O.

After extrusion, the extrudate may be dried using any convenient means such as a multiple-pass dryer/cooler. The moisture content of the extrudate as it emerges from the die is normally from about 25-32% by weight, and more preferably from about 27-29% by weight.

As explained above, the method of the invention preferably involves the step of measuring a density value of extrudate and adjusting the magnitude of the reduced pressure conditions within the barrel in response to such measurement(s). It will be appreciated that this technique is not limited to the production of high protein, high fat extrudates, but can be used to good effect in a wide variety of extrusion technologies where density control is considered important. Thus, this aspect of the invention involves providing a starting mixture for extrusion which is subsequently passed into and through an extruder and extrusion die while creating a condition of reduced pressure at a zone along the length and within the barrel upstream of the die. The density value (preferably bulk density) of the extrudate is used as a guide to adjust the reduced pressure conditions within the barrel zone.

BRIEF DESCRIPTION OF THE DRAWING

The single Figure is an essentially schematic illustration of the preferred extrusion system used in the production of the feeds of the invention.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

In general, the preferred equipment used in carrying out the invention (see the Figure) includes an extrusion system 10 broadly comprising a preconditioner 12, and a 5-head extruder 14 equipped with a mid-barrel vent/vacuum device 16. Preferably, the overall system 10 includes density valve measuring apparatus 18 operably coupled with a microprocessor controller 20, the latter operating a motor 22 in turn coupled with vacuum pump 24; as shown, the vacuum pump 42 is operably connected with the device 16.

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In more detail, the preconditioner 12 is a Wenger DDC preconditioner (Wenger Manufacturing, Inc., Sabetha, KS) of the type described in U.S. Patent No. 4,752,139, which is incorporated by reference herein. The purpose of preconditioner 12 is to moisten and initially cook to a limited degree the starting dry ingredients, as is well understood in the art. In addition, in preferred forms, fish oil may be injected into the preconditioner and mixed with the dry ingredients together with water and steam. As shown, the outlet of the preconditioner feeds directly to the inlet of extruder 14.

In the form shown, extruder 14 is a Wenger TX85 twin screw extruder including a total of five interconnected tubular heads 26-34 defining an elongated, tubular barrel 36, as well as a pair of intermeshing, axially rotatable, powered flighted screws (not shown) within the barrel 36. The extruder is of the type described in U.S. Patent No.4,875,847, incorporated by reference herein. In more detail, the extruder 14 includes inlet head 26 having an upright material inlet 38 operatively coupled with the outlet of preconditioner 12. The third head 30 is apertured and supports device 16. Outlet head 34 is equipped with a multi-orifice die 40 as shown. The heads 28-34 are equipped with external jackets for the circulation of heating or cooling media; moreover, these heads are also provided with ports for the direct injection of steam and/or moisture into the extruder barrel.

In use, the flighted auger screws within barrel 36 are rotated in order to transport incoming preconditioned material from inlet 38 to and through the restricted orifices of die 40. During such movement, the material is subjected to increasing levels of temperature, pressure and shear in order to cook the product to the desired extent and form the extrudate into a desired shape. To this end, extrusion apparatus of this type is also normally equipped with rotating knife structure (not shown) adjacent die 40 which serves to subdivided the extrudate emerging from the die orifices.

The device 16 is a vent/vacuum apparatus adapted for drawing gas from the extruder barrel 36 during operation of extruder 14. The device 16 is fully described in U.S. Patent No. 4,763,569, incorporated by reference herein. Briefly, however, the device 16 includes an upright housing 42 including a lowermost cylindrical portion 44 operably secured to head 30, as well as an upper conical portion 46. When mounted on head 30, the interior 48 of housing 42 is in communication with the interior of barrel 36. the overall device 16 further includes an upright internal screw 50 within housing 42. The screw 50 is flighted and serve to substantially prevent entrance of solid material from barrel 36 into the housing interior. The screw 50 is axially rotatable by means of motor 52 and right angle drive 54. A gas outlet pipe 56 extends through the

top of housing 42 as shown, and communicated with the interior 48 of the housing. The pipe 56 may be directly vented to the atmosphere, or in preferred forms, is connected to vacuum pump 24, the latter being operated through the medium of motor 22.

Density measuring apparatus 18 is of conventional construction, and operates to allow essentially continuous or selective measurement of the bulk density of the subdivided extrudate from die 40. Such bulk density data can then be used in a feedback loop manner to increase or decrease the magnitude of the vacuum applied to the extruder barrel 36 via device 16. That is, if the bulk density is too low, the vacuum level may be increased; alternately, if the measured bulk density is too high, the level of vacuum may be decreased. In this connection, those skilled in the art will readily appreciate that controller 20 is of conventional design and operation, and may be a part of a more sophisticated microprocessor control system associated with the overall operation of system 10. In any case, it will be understood that provision of apparatus 18, controller 20, motor 22 and pump 24 allows selective control of the vacuum applied to barrel 36 in response to variations in the bulk density of the product emerging from the extruder.

Although not shown, the overall system 10 would also normally include a conventional dryer serving to dry the extrudate down to an acceptable moisture level for extended storage and use. A multiple-pass Wenger dryer can be employed to good effect. Additionally, the equipment may include coating apparatus for external coating of the extrudate with liquid fat.

The following example sets forth preferred procedures in accordance with the invention. This example is provided as an illustration only, and nothing therein should be taken as a limitation upon the overall scope of the invention.

EXAMPLE

A large number of extrusion tests were carried out to fabricate various types of sinking aquatic feed pellets.

Table 1 sets forth the preconditioner, extruder and die and knife configurations employed in carrying out the tests of this Example. In all cases, the parts numbers employed are Wenger Manufacturing, Inc. parts numbers for the respective pieces of equipment.

Table 1

PRECONDITIONER CONFIGURATION

LEFT SHAFT

Quantity	Degree	Type	Position
12	75	beater	forward
24	90	beater	neutral
24	-75	beater	reverse

RIGHT SHAFT

Quantity	Degree	Type	Position
12	75	beater	forward
48	-75	beater	reverse
--	--	--	--

EXTRUDER CONFIGURATION #1

Heads

1. 53916-001
2. 53907-001
3. 53916-001
4. 53907-001
5. 53919-001

ROTATING ELEMENTS

1. 53657-003	6. 53624-105 F	11. 53625- 103	16. 53657-003	21. 53624-103 F	26. 53626-007
2. 53657-003	7. 53624-105 O	12. 53624-101 O	17. 53657-003	22. 53624-105 F	27. 53626-103
3. 53657-003	8. 53624-103 F	13. 53624-105+	18. 53625-003	23. 53624-105 O	28. 53626-003
4. 53624-101 O	9. 53624-101 F	14. 53624-101+	19. 53625-003	24. 53624-103 F	29. 53626-103
5. 53625-103 F	10. 53625-003	15. 53657-003	20. 53624-101 O	25. 53624-101 F	30. 53626-003
					31. 53620-00

EXTRUDER SHAFT: 53622-003   RIGHT SHAFT: 1.43657-203; 2. 53657-203

EXTRUDER CONFIGURATION #2

Heads

1. 53916-001
2. 53907-001
3. 53916-001
4. 53907-001
5. 53919-001

ROTATING ELEMENTS

1. 53657-003	6. 53624-105 F	11. 53624-101+	16. 53626-103	21. 53657-003	26. 53625-003
2. 53657-003	7. 53624-103 F	12. 53624-105+	17. 53624-101 R.	22. 53657-003	27. 53625-003
3. 53657-003	8. 53624-101 F	13. 53624-101+	18. 53624-103 R	23. 53657-003	28. 53621-005
4. 53624-101 O	9. 53625-003	14. 53624-105+	19. 53624-105 R	24. 53625-003	--
5. 53625-103 F	10. 53625-103	15. 53625-003	20. 53625-003	25. 53625-003	--

DIE AND KNIFE CONFIGURATION #1

KNIFE INFORMATION	DIES AND ADAPTORS	
Knife Blade 19430-007	1. 53661-001 AD	4. 74010-699 NA	7. 74010-879 NA
No. of Knife Blades: 1	2. 74010-870 NA	5. 31600-545 BT	1 insert, 20 mm diameter
Knife Holder 19462-001	3. 74010-882 NA	6. 74010-839 NA	

DIE AND KNIFE CONFIGURATION #12

KNIFE INFORMATION	DIES AND ADAPTORS	
Knife Blade 19430-007	1. 53661-001 AD	4. 74010-699 NA	7. 74010-879 NA
No. of Knife Blades: 1	2. 74010-870 NA	5. 31600-545 BT	1 insert, 20 mm diameter
Knife Holder 19462-001	3. 74010-882 NA	6. 74010-839 NA	

DIE AND KNIFE CONFIGURATION #13

KNIFE INFORMATION	DIES AND ADAPTORS	
Knife Blade 19430-007	1. 53661-001 AD	4. 74010-699 NA	7. 74010-879 NA
No. of Knife Blades: 6	2. 74010-870 NA	5. 31600-545 BT	6 inserts, 6 mm diameter
Knife Holder 19462-001	3. 74010-882 NA	6. 74010-839 NA	

DIE AND KNIFE CONFIGURATION #4

KNIFE INFORMATION	DIES AND ADAPTORS	
Knife Blade 19430-007	1. 53661-001 AD	4. 74010-699 NA	7. 74010-879 NA
No. of Knife Blades: 1	2. 74010-870 NA	5. 31600-545 BT	1 insert, 20 mm diameter
Knife Holder 19462-015	3. 74010-882 NA	6. 74010-839 NA	

DIE AND KNIFE CONFIGURATION #5

KNIFE INFORMATION	DIES AND ADAPTORS	
Knife Blade 19430-007	1. 53661-001 AD	4. 74010-699 NA	7. 74010-880 NA
No. of Knife Blades: 1	2. 74010-870 NA	5. 31600-545 BT	1 insert, 20 mm diameter
Knife Holder 19462-015	3. 74010-882 NA	6. 74010-839 NA	

DIE AND KNIFE CONFIGURATION #6

KNIFE INFORMATION	DIES AND ADAPTORS	
Knife Blade 19430-007	1. 53661-001 AD	4. 74010-699 NA	7. 74010-752 NA
No. of Knife Blades: 3	2. 74010-870 NA	5. 31600-545 BT	5 insert, 6 mm diameter
Knife Holder 19462-015	3. 74010-882 NA	6. 65421-001 BH	

DIE AND KNIFE CONFIGURATION #7

KNIFE INFORMATION	DIES AND ADAPTORS	
Knife Blade 19430-007	1. 53660-001 AD	4. 74010-803 NA	7. –
No. of Knife Blades: 1	2. 27361-625 BH	5. --	10 inserts, 6 mm diameter
Knife Holder 19462-001	3. --	6. –	

| 5. 53919-001 | 5. 53625-103 F | 10. 53625-103 | 15. 53625-003 | 20. 53625-003 | 25. 53625-003 | -- |

EXTRUDER SHAFT: 53622-003; RIGHT SHAFT: 1. 53657-203; 2. 53657-203; 3. 53657-203

In a first series of six extrusion tests, three separate starting dry ingredient recipes were employed. These recipes are set forth in Table 2.

Table 2

Ingredients (% by wt.)	Recipe #1	Recipe #2	Recipe #3
Fish Meal	62.56	72.31	68.07
Wheat Flour	12.03	--	10.00
Tapioca Starch (precooked)	14.81	16.55	10.87
Corn Gluten Meal	5.00	5.00	5.00
Minor Ingredients	5.60	6.14	5.96
Total	100	100	100

Table 3 sets forth the equipment and recipes used, as well as the recorded preconditioning, extrusion and final product information for Runs #1-6. In Table 3, "CW" refers to the fact that cold water was circulated through the jackets of the extruder barrel heads for cooling purposes; and the mid-barrel vacuum data refers to the magnitude of the vacuum drawn through the device 16 referred to above. Also, fish oil (sardine oil) was injected into the starting ingredients during preconditioning, at the rates described. In Runs #1-3 and 6, all of the total fish oil content was injected into the preconditioner and was deemed to be "internal"; in Runs #4 and 5, a proportion of the total fish oil content was injected into the preconditioner as internal fish oil, and another proportion was applied externally to the pellets after drying thereof.

Table 3

		Run #1	Run #2	Run #3	Run #4	Run #5	Run #6
DRY RECIPE INFORMATION							
Dry Recipe Moisture	% wb	7.19	7.19	7.19	7.19	7.19	7.19
Dry Recipe Rate	kg/hr.	950	610	700	650	650	650
Feed Screw Speed	rpm	66	39	--	41	44	69
PRECONDITIONING INFORMATION							
Preconditioner Speed	rpm	250	250	250	250	250	250
Steam Flow to Preconditioner	kg/hr.	85	55	70	84	84	133
Water Flow to Preconditioner	kg/hr.	162	104	119	117	117	117
Preconditioner Fish Oil Rate	kg/hr.	167	107	123	114	60	167
Preconditioner Discharge Temperature	°C	83	81	--	94	92	97
Moisture Entering Extruder	% wb	21.21	20.98	21.17	24.10	21.09	20.69
EXTRUSION INFORMATION							
Extruder Shaft Speed	rpm	404	404	404	404	404	404
Extruder Motor Load	%	36	33	00	32	35	32
Water Flow to Extruder (barrel injection)	kg/hr.	95	55	56	78	78	57
Steam Flow to Extruder (barrel injection)	kg/hr.	0	0	49	32	31	76
Control/Temperature 1st Head	°C	CW/59	CW/56	CW/56	CW/64	CW/61	CW/66
Control/Temperature 2nd Head	°C	CW/43	CW/41	CW/41	CW/58	CW/51	CW/59
Control/Temperature 3rd Head	°C	CW/49	CW/47	CW/47	CW/49	CW/47	CW/50
Control/Temperature 4th Head	°C	CW/82	CW/73	CW/73	CW/74	CW/82	CW/82
Control/Temperature 5th Head	°C	CW/73	CW/70	CW/70	CW/68	CW/68	CW/73
Mid-Barrel Vacuum	in. Hg	--	--	--	11	11	10
5th Head/Pressure	kPa	1520	1380	--	1030	1380	1720
Knife Drive Speed	rpm	1455	1748	--	1065	837	--
FINAL PRODUCT INFORMATION							
Extruder Discharge Moisture	% wb	26.58	26.11	26.74	28.83	31.87	25.16
Extruder Discharge Rate	kg/hr.	--	--	--	1034	1006	1554
Extruder Discharge Density	kg/m³	593	--	641	655	641	593
Extruder Performance		Stable	Stable	Stable	Stable	Stable	Stable

		Run #1	Run #2	Run #3	Run #4	Run #5	Run #6
REFERENCE INFORMATION							
Recipe No.		1	1	2	3	3	1
Extruder Configuration		1	1	2	2	2	2
Die and Knife Configuration		2	1	1	3	3	2

A second set of extruder tests were also conducted (Runs #7-30) using a series of different recipes and conditions. The individual recipes employed basic Formulas A or B (Table 4, and the complete recipes (Nos. 4-23) are set forth in Table 5.

Table 4

Basic Formulae

Ingredients (% by wt.)	Formula A	Formula B
Fish Meal	76.47	83.30
Wheat Flour	14.71	--
Vitamin/Nutrient Mixture	2.94	3.37
Tapioca Starch (precooked)	5.88	13.33
Total	100	100

Table 5

Ingredients % By Weight							
Recipe #	Formula A	Formula B	Wheat Flour	Corn Gluten	Rework[1]	Tapioca Starch (precooked)	Minor Ingredients
4	--	81.73	9.97	5.00	--	--	3.30
5	--	81.42	5.00	5.00	5.00	--	3.59
6	--	76.39	5.00	5.00	10.00	--	3.61
7	--	79.70	--	5.00	5.00	7.00	3.30
8	--	79.70	--	5.00	5.00	7.00	3.30
9	--	76.73	--	5.00	10.00	6.98	1.30

Ingredients % By Weight							
10	82.67	--	--	5.01	5.01	5.01	1.20
11	84.68	--	--	5.00	5.00	5.00	0.31
12	79.27	--	10.21	5.10	51.0	--	0.30
13	81.73	--	7.43	5.26	5.26	--	0.32
14	83.72	--	--	5.39	5.26	--	0.32
15	84.68	--	--	5.00	5.00	5.00	0.31
16	84.68	--	5.00	5.00	5.00	--	0.31
17	88.74	--	1.01	4.97	4.97	--	0.30
18	--	82.87	--	5.02	5.02	7.00	0.08
19	--	87.90	--	4.99	4.99	2.00	0.11
20	--	84.90	--	5.00	5.00	5.00	0.10
21	--	89.95	--	4.97	4.97	--	0.10
22	85.90	--	--	5.00	5.00	--	4.10
23	--	84.88	--	5.01	5.01	5.01	0.10

The equipment used, extrusion conditions recorded, and product properties are set forth in Table 6. In Runs #7 and 17, a proportion of the total fish oil was applied externally after drying of the pellets; in all other runs, the total fish oil content was injected into the preconditioner. In Runs #8 and 17, a part of each test was carried out without vacuum, merely venting the atmosphere; the products produced without vacuum treatment were less desirable.

Table 6

		Run #7	Run #8	Run #9	Run #10	Run #11	Run #12	Run #13	Run #14	Run #15	Run #16	Run #17	Run #18
DRY RECIPE INFORMATION													
Dry Recipe Density	kg/m³	481	481	481	481	481	481	481	481	481	481	481	481
Dry Recipe Rate	kg/hr.	700	700	700	700	700	700	700	700	700	950	950	950
Feed Screw Speed	rpm	45	46	45	44	42	43	42	41	42	62	57	64
PRECONDITIONING INFORMATION													
Preconditioner Speed	rpm	250	250	250	250	250	250	250	250	250	250	250	250
Steam Flow to Preconditioner	kg/hr.	77	77	77	77	77	70	70	70	70	123	123	85
Water Flow to Preconditioner	kg/hr.	91	95	98	105	112	112	112	98	98	143	143	142
Preconditioner Fish Oil Rate	kg/hr.	190	233	154	154	175	125	116	116	168	90	90	90
Preconditioner Discharge Temperature	°C	91	89	86	86	83	94	94	95	--	90	90	82
Moisture Entering Extruder	% wb	20.12	--	19.96	21.68	21.01	21.06	20.53	20.14	19.88	19.08	--	20.65
EXTRUSION INFORMATION													
Extruder Shaft Speed	rpm	434	434	430	430	434	432	431	432	428	425	425	405
Extruder Motor Load	%	30	30	31	31	31	31	31	33	31	32	35	36
Water Flow to Extruder (barrel injection)	kg/hr.	32	49	56	49	51	49	49	35	35	47	68	57
Steam Flow to Extruder (barrel injection)	kg/hr.	91	56	72	78	74	63	65	63	61	85	25	34
Control/Temperature 1st Head	°C	CW/69	CW/63	CW/63	CW/63	CW/60	CW/61	CW/60	CW/60	CW/61	CW/63	CW/65	CW/55
Control/Temperature 2nd Head	°C	CW/55	CW/57	CW/56	CW/55	CW/55	CW/52	CW/51	CW/55	CW/53	CW/57	CW/54	CW/50
Control/Temperature 3rd Head	°C	CW/62	CW/66	CW/51	CW/51	CW/84	CW/48	CW/45	CW/47	CW/48	CW/52	CW/54	CW/54

		Run #7	Run #8	Run #9	Run #10	Run #11	Run #12	Run #13	Run #14	Run #15	Run #16	Run #17	Run #18
Control/Temperature 4th Head	°C	CW/92	CW/69	CW/65	CW/69	CW/71	CW/69	CW/68	CW/72	CW/69	CW/96	CW/92	CW/76
Control/Temperature 5th Head	°C	CW/69	CW/56	CW/62	CW/63	CW/63	CW/64	CW/66	CW/70	CW/67	CW/71	CW/71	CW/65
Mid-Barrel Vacuum	in. Hg	8	10	--	10	11	11	12	12	12	9	10	11
5th Head/Pressure	kPa	860	--	--	340	340	340	690	520	340	1380	130	1900
Die Pressure	psi	428	--	--	345	379	379	379	413	551	413	413	345
Knife Drive Speed	rpm	1293	1293	1585	--	1455	--	1357	1390	1422	1065	1065	1130
FINAL PRODUCT INFORMATION													
Extruder Discharge Moisture	% wb	26.02	--	25.10	26.87	24.84	25.03	28.39	27.24	24.50	26.86	27.42	28.84
Extruder Discharge Rate	kg/hr.	853	--	--	--	1000	--	--	--	--	1336	--	--
Extruder Discharge Density	kg/m³	577	609	577	657	689	689	689	689	689	673	689	689
Dryer Discharge Moisture	% wb	--	--	--	--	15.07	14.03	15.31	13.78	12.42	14.90	16.58	17.62
Dryer Discharge Density	kg/m³	577	609	577	561	577	577	609	593	593	509	625	641
Extruder Performance		Stable	Stable	Stable	Stable	Stable	Stable	Stable	Stable	Stable	Stable	Stable	Stable
REFERENCE INFORMATION													
Recipe No.		4	4	5	6	7	8	8	9	9	10	11	12
Extruder Configuration		2	2	2	2	2	2	2	2	2	2	2	2
Die and Knife Configuration		4	4	4	4	4	4	4	4	4	5	5	5

		Run #19	Run #20	Run #21	Run #22	Run #23	Run #24	Run #25	Run #26	Run #27	Run #28	Run #29	Run #30
DRY RECIPE INFORMATION													
Dry Recipe Density	kg/m³	481	481	--	481	481	481	481	481	481	481	481	481
Dry Recipe Rate	kg/hr.	950	950	700	700	700	600	600	600	600	700	700	700
Feed Screw Speed	rpm	61	56	42	41	44	38	36	36	37	41	40	45
PRECONDITIONING INFORMATION													
Preconditioner Speed	rpm	250	250	250	250	250	250	250	250	250	250	250	250
Steam Flow to Preconditioner	kg/hr.	85	85	63	64	66	54	48	48	41	84	84	77
Water Flow to Preconditioner	kg/hr.	142	143	105	105	105	90	90	102	108	105	105	91
Preconditioner Fish Oil Rate	kg/hr.	91	90	66	66	16	144	144	144	145	113	113	168
Preconditioner Discharge Temperature	°C	98	90	91	92	94	80	83	86	83	86	94	95
Moisture Entering Extruder	% wb	21.93	22.87	21.41	21.54	20.70	--	--	22.27	--	21.71	20.51	--
EXTRUSION INFORMATION													
Extruder Shaft Speed	rpm	406	400	400	401	400	377	377	380	376	450	451	430
Extruder Motor Load	%	36	35	32	32	33	33	34	33	33	31	29	32
Water Flow to Extruder (barrel injection)	kg/hr.	57	57	42	42	42	45	48	90	96	84	91	32
Steam Flow to Extruder (barrel injection)	kg/hr.	24	24	21	21	21	0	0	0	0	77	77	77
Control/Temperature 1st Head	°C	CW/45	CW/60	CW/57	CW/60	CW/60	CW/55	CW/55	CW/58	CW/58	CW/61	CW/61	CW/66
Control/Temperature 2nd Head	°C	CW/50	CW/50	CW/52	CW/51	CW/51	CW/48	CW/46	CW/45	CW/45	CW/53	CW/55	CW/62
Control/Temperature 3rd Head	°C	CW/55	CW/56	CW/55	CW/56	CW/55	CW/45	CW/43	CW/44	CW/45	CW/46	CW/52	CW/51
Control/Temperature 4th Head	°C	CW/50	CW/78	CW/73	CW/70	CW/69	CW/71	CW/66	CW/69	CW/69	CW/69	CW/95	CW/75

		Run #19	Run #20	Run #21	Run #22	Run #23	Run #24	Run #25	Run #26	Run #27	Run #28	Run #29	Run #30
Control/Temperature 5th Head	°C	CW/40	CW/68	CW/66	CW/67	CW/68	CW/56	CW/56	CW/57	CW/56	CW/64	CW/64	CW/65
Mid-Barrel Vacuum	in. Hg	11	11	11	11	11	10.5	12	12	15	11	Vent only No Vac.	10
5th Head/Pressure	kPa	1900	1790	1720	1580	1720	1380	1030	860	690	690	620	1210
Die Pressure	psi	449	427	517	517	482	620	689	551	551	551	--	413
Knife Drive Speed	rpm	1130	1130	1748	1650	1650	--	545	675	935	1000	1552	1357
FINAL PRODUCT INFORMATION													
Extruder Discharge Moisture	% wb	27.31	27.25	27.52	27.49	26.24	--	26.43	28.56	--	30.97	31.58	--
Extruder Discharge Rate	kg/hr.	1298	--	983	--	--	--	--	--	--	--	--	--
Extruder Discharge Density	kg/m³	689	689	689	389	389	--	785	753	753	--	721	689
Dryer Discharge Moisture	% wb	17.44	18.77	10.17	10.24	--	15.20	12.37	15.26	--	15.34	11.89	12.37
Dryer Discharge Density	kg/m³	673	657	593	561	561	625	577	609	593	641	577	593
Extruder Performance		Stable	Stable	Stable	Stable	Stable	Stable	Stable	Stable	Stable	Stable	Stable	Stable
REFERENCE INFORMATION													
Recipe No.		13	14	15	16	17	18	20	19	21	22	22	23
Extruder Configuration		2	2	2	2	2	2	2	2	2	2	2	2
Die and Knife Configuration		5	5	4	4	4	6	6	6	6	6	7	4

The following table gives the final ingredient makeup and properties of the feed pellets produced in Runs #7-30.

Table 7

Ingredients (% by wt.)	7	8	9	10	11	12	13	14	15	16	17	18
Fish Meal	51.50	51.50	52.74	48.95	50.06	47.10	48.56	49.74	50.06	43.20	48.72	49.78
Added Fish Oil	20	20	20	20	20	20	20	20	20	20	20	25
Internal Fish Oil	7	7	7	7	7	7	7	7	7	7	7	7
Total Fish Oil	27	27	27	27	27	27	27	27	27	27	37	32
Wheat Flour	0	0	0	9.42	9.63	16.51	14.73	9.57	9.63	11.46	10.05	0
Tapioca Starch	13.3	13.3	13.5	8.86	7.49	3.62	3.73	7.76	7.49	3.32	3.74	12.73
Corn Gluten Meal	3.6	3.6	3.6	3.6	3.6	3.72	3.83	3.93	3.6	3.15	3.38	3.41
Minor Ingredients	4.5	4.5	3.41	3.1	2.14	2.02	1.86	1.99	2.15	1.86	2.08	1.85
Moisture	9.1	8.7	9.6	9.1	7.7	8.1	9.0	8.7	8.8	8.1	9.3	10.1
Bulk Density (kg/cm)	577	609	577	561	577	609	593	593	609	625	609	625
Specific Gravity	--	--	--	--	--	--	--	--	--	--	--	--
Length/Diameter	--	--	--	--	--	--	--	--	--	--	--	--

Run No.

Ingredients (% by wt.)	Run No.											
	19	20	21	22	23	24	25	26	27	28	29	30
Fish Meal	52.62	50.93	49.81	50.74	58.10	37.10	44.10	39.50	45.20	47.20	56.60	41.30
Added Fish Oil	25	25	22	20	15	27	20	20	20	20	22	27
Internal Fish Oil	7	7	7	7	7	7	7	7	7	7	7	7
External Fish Oil	32	32	37	37	22	34	27	27	27	27	22	25
Wheat Flour	0	0	0	9.76	0	9.45	9.45	12.1	10	10	0	10
Tapioca Starch	9.78	11.55	7.97	3.89	13.25	13.6	13.6	9.9	7.9	6.5	15.8	10.5
Corn Gluten Meal	3.39	3.4	3.13	3.65	3.91	3.91	3.83	3.83	3.83	3.83	3.83	3.83
Minor Ingredients	2.2	2.12	2.04	4.94	2.44	1.99	1.99	4.05	4.05	4.05	4.05	4.05
Moisture	6.5	6.4	6.5	7.8	6.17	7.5	10.7	9.9	9.6	9.6	9.6	7.8
Bulk Density (kg/cm)	641	673	657	593	561	625	577	609	641	577	609	593
Specific Gravity	--	--	--	0.9	0.87	--	--	--	--	1.2	1.23	--
Length/Diameter	--	--	--	7.8/6.6	8.1/6.4	--	--	--	--	8.7/5.0	9.2/6.0	--

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An additional two extrusion runs were conducted in a manner similar to those described in detail above. During the course of each run, the mid-barrel vacuum source was turned off to determine the effect upon the ultimate pellets. In the first run (Run #31), recipe #11 (with 15% internal fat), extruder configuration #2, and die and knife configuration #5 were employed, along with the same preconditioner configuration of the previous examples. During the bulk of Run #31, the mid-barrel device was operated at 10 inches Hg of vacuum. In the middle of the run for a period of about 5 minutes, the vacuum source was turned off, causing rapid barrel heating. Products from the vacuum-on and vacuum-off portions of the run were collected and were analyzed for fines. During the vacuum-off stage, the products exhibited 15.78% by weight fines, while in the vacuum-on stage, the fines were only 5.13% by weight.

In another comparative run (Run #32), recipe #4 was used (with 30% total internal fat), using the above preconditioner configuration, extruder configuration #2 and die and knife configuration #4. During the majority of the run, the mid-barrel vacuum device was maintained at 10 inches Hg but as above for a short period the vacuum was turned off. The resultant products from the vacuum-off stage exhibited 91.15% by weight fines, while the vacuum-on products had only 19.05% by weight fines.

The test procedure used to determine fines is set forth in *Feed Manufacturing Technology IV*, American Feed Industry Association, Inc., 1994, p.122, which is incorporated by reference herein.

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We claim:

1.   A method of preparing a high protein, high fat sinking aquatic feed comprising the steps of:

>   providing a starting mixture including from about 15-55% by weight protein and at least about 1% by weight starch;
>
>   preconditioning said starting mixture by adding moisture thereto and subject the starting mixture to conditions of elevated temperature and agitation; and
>
>   passing the preconditioned starting mixture into and through an extruder having an elongated barrel with an elongated, axially rotatable, flighted screw therein and an endmost extrusion die to form a self-sustaining extrudate having a specific gravity of greater than 1,
>
>   said passing step including the step of creating a condition of reduced pressure at a zone along the length of and within said barrel upstream of said die for densifying the preconditioned starting mixture within said barrel,
>
>   said method further including the step of adding fat to said starting mixture and/or extrudate so that the extrudate has a total fat content of from about 10-40% by weight.

2.   The method of claim 1, including the step of measuring a density value of said extrudate, and adjusting the magnitude of said reduced pressure in response to said density value measurement.

3.   The method of claim 2, wherein said density value is bulk density.

4.   The method of claim 1, including the step of adding liquid fat to said starting mixture during said preconditioning step.

5.   The method of claim 1, including the step of subjecting said starting mixture to a temperature of from about 75-98°C for a period of from about 150-200 seconds during said preconditioning step.

6.   The method of claim 1, including the step of adding fat to said starting mixture during said preconditioning step.

7.   The method of claim 1, including the step of applying fat to said extrudate as a surface coating.

8.   The method of claim 1, including the step of adjusting the moisture content of said extrudate to a level of from about 25-32% by weight.

9.   The method of claim 1, including the step of subjecting said preconditioned starting material to conditions of elevated heat, pressure and shear during passage thereof through said extruder.

10.   The method of claim 9, wherein preconditioned starting mixture is heated to a temperature of from about 50-95°C in said barrel, and subjected to a maximum temperature of from about 100-500 psi therein.

11.   The method of claim 9, wherein said material is heated to a temperature maximum prior to reacting said zone.

12.   The method of claim 1, said creating step comprising drawing a partial vacuum in said zone.

13.   The method of claim 11, said partial vacuum having a magnitude of from about 2-15 inches Hg.

14.   The method of claim 1, including the step of drying said extrudate.

15.   An extrusion method comprising the steps of:
providing a starting mixture;
passing said starting mixture into and through an extruder having an elongated barrel with an elongated axially rotatable, flighted screw therein and an endmost extruder die to form an extrudate,
said passing step including the step of creating a condition of reduced pressure at a zone along the length of and within said barrel upstream of said die;
measuring a density value of said extrudate, and adjusting the magnitude of said reduced pressure in response to said density value measurement.

16.　　　The method of claim 15, wherein said material is heated to a temperature maximum prior to reacting said zone.

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